Section 3.4

High Level Waste Melter Feed Line Failure

BNFL Inc.

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High Level Waste Melter Feed Line Failure

3.4.1 Work Identification

This section demonstrates an application of the integrated safety management process to an example of high level waste melter feed line failure. This report focuses on control of hazards associated with a breach of the high level waste melter feed line leading to a release of process material into the melter cave.

The concentrated high level waste (HLW) slurry is combined with Sr/TRU precipitate, Cs and Tc concentrate, and the recycle from the HLW melter quencher sump to produce a blended slurry. This blended slurry is then mixed with dry, glass-forming chemicals. The resultant waste/glass former slurry is transferred to the HLW melter feed vessel (V11002). This feed slurry is then pumped to the HLW melter (V12001) where vitrification occurs. This example examines the consequences of a breach of the melter feed line from the melter feed vessel to the HLW melter. Such a breach could potentially result in exposures to the facility worker, the co-located worker, and the public.

The basis used for this example is the *HLW Melter System 90 Percent Conceptual Design Report Rev 0*, September 10, 1997, GTS Duratek, BNFL Inc.

3.4.1.1 Key Process and Design Parameters

The function of the HLW melter has been described in section 3.4.1. The functions of the melter feed preparation system will be described in section 3.4.1.1.1.

3.4.1.1.1. Process

The HLW melter feed preparation system (see Figure 3.4-1) consists of a HLW melter feed preparation vessel (V11001) and a melter feed vessel. The feed preparation vessel and the melter feed vessel are sized to allow the entire contents of the feed preparation vessel to be transferred to the melter feed vessel as a single batch. The melter feed vessel will feed continuously to the melter. The melter feed will be pumped to the HLW melter through two melter feed lines at a combined average rate of 150 L/h. (BNFL Engr. Ltd 1998, Stream 118). **Operational Assumption**

The feed will be vitrified in an HLW melter which will have an integral cooling water jacket. The operating temperature of the melter will be between 1,100 and 1,200 ºC. The nominal throughput of the HLW melter system will be 1.5 metric tons (t) of glass per day.

The material at risk for the transfer of the waste and glass formers to the HLW melter comprises a blend of the HLW sludge (derived from 241-AZ-101) and the separated radionuclides from pretreatment. Tank 241-AZ-101 was selected as the basis for the source of radionuclides because it contains the highest concentration of radionuclides of concern among the three candidate HLW feed tanks. The blending of these streams is carried out upstream of the HLW melter feed vessel. The waste is only fed to the HLW melter following the addition of glass formers within the HLW feed preparation vessel (V11001) located upstream from the melter feed vessel. Hence, the material in the feed line will be blended wastes and glass formers. The incorporation of the waste into the HLW melter is limited by the glass chemistry requirements and the heat generation restriction of 1500 W per HLW canister (DOE-RL 1998a, Specification 1). These limits result in the following selected radionuclides:

Radionuclide	Concentration Curies/liter	Basis
^{137}Cs	30	Tank 241-AZ-101 activity adjusted for feed to melter
^{90}Sr	11	Tank 241-AZ-101 activity adjusted for feed to melter
^{99}Tc	0.003	Tank 241-AZ-101 activity adjusted for feed to melter
^{239}Pu	0.002	Tank 241-AZ-101 activity adjusted for feed to melter
^{241}Am	0.052	Tank 241-AZ-101 activity adjusted for feed to melter

3.4.1.1.2. Design

The 2750 US gal (10.4-m^3) melter feed vessel is sized to accept a 48-hour supply of makeup from the feed preparation vessel. The melter feed vessel is equipped with mechanical agitation and a vessel vent system for offgas treatment. Because of the heat generating capacity of the feed material, cooling must be provided in order to optimize the temperature at which the feed is pumped to the melter. Cooling is provided by water-cooled jackets on the exterior of the vessel (BNFL Inc. 1998a). To ensure adequate mixing, the feed vessel is not allowed to operate below 40% of working volume. The HLW melter feed vessel is fitted with two feed pumps. Each pump supplies a single feed nozzle on the HLW melter. The feed lines, which are stainless steel tubing, have remotely removable sections and fittings in locations with a high potential for erosion or blockage. The total length of the feed line will determine the actual flow velocity and pump stroke time.

It is anticipated that fluidic pumps will be used to transfer the melter feed from the feed vessel to the melter. The choice will be between either air displacement slurry (ADS) pumps, as are used at West Valley, or reverse flow diverter (RFD) or diode pumps, as are used at Sellafield (BNFL Inc 1997). The Part A design reflected the use of ADS pumps; therefore, the ADS pump is the one used in development of this worked example.

The ADS pump has a 0.5-US gal (2-L) displacement chamber. Since there will be two feed nozzles, two ADS pumps are required in the feed vessel. The ADS pump has low air volume and air pressure (30 to 50 psig) requirements. **Design Assumption.** Each ADS pump is connected to one feed nozzle on the melter via an individual feed line. The two feed pumps operate simultaneously during a feeding cycle to supply the two feed nozzles on the melter at the required combined flow rate of 40 gph (150 L/h). However, either feed pump and line is capable of providing the required 40 gph (150 L/h) (BNFL Inc. 1997).

Heat will be conducted from the inside of the melter to the melter top. It is believed that the top of the melter may reach temperatures ranging from 212 to 302 ºF (100 to 150 ºC) based on GTS Duratek operational experience. **Design Assumption**.

3.4.1.2 Interfaces

The HLW melter feed vessel receives feed from the HLW melter feed preparation vessel. The feed is then pumped on a continuous basis to the HLW melter via the HLW melter feed line. The feed is pumped to the melter using two ADS pumps, each requiring about 0.1scfm (0.17 scmh) of utility air at a nominal 30 to 50 psig (2 to 3.5 barg) maximum during a feed cycle. This arrangement is shown in BNFL Inc. 1998a.

The cave structure provides secondary containment and shielding. Ventilation is provided to the melter cave via a cascade system. The cave ventilation system provides cooling to the cave environment in which the vessel and melter are located and maintains the cave at a negative pressure with respect to occupied areas of the facility. The cave ventilation system also provides filtration prior to exhausting the air to the environment. Vessels are ventilated using the vessel ventilation system.

3.4.1.3 Operating Environment and Setting

The HLW melter feed vessel and the melter are located in the melter cave (BNFL Inc. 1998b) with dimensions of 145 ft x 50 ft x 67 ft high (44 m x 15 m x 20.5 m high) (BNFL Inc. 1998c). The feed vessel will be located as close to the HLW melter as practical (BNFL Inc. 1998b and 1998d) to minimize both the total length and the number of bends required in the feed pipework. Radiation levels dictate that all equipment will be designed for remote operation and maintenance. It is anticipated that, due to the abrasive and corrosive nature of the feed slurry, vessels, agitators, and pumps will need to be replaced within the lifetime of the plant. The melter cave will have multiple viewing windows to allow for operating personnel to see inside. **Design Assumption.**

The operating environment in the melter cave will be radiologically onerous, i.e., high gamma radiation fields, significant contamination, surfaces will become coated with deposits of abrasive contaminated solids (arising from remote maintenance activities and spillages). The cave temperature will be higher than normal due to the melter. The actual temperature remains to be calculated when the cave layout and ventilation system design is finalized. **Open Issue.**

In the melter cave, the maintenance tools for the replacement duties will consist of a 10-ton overhead crane and situated beneath it, a 5-ton overhead crane combined with a power manipulator of limited capacity (e.g., 150-lb lift at full reach, dependent upon final model or type selected). To control contamination buildup on the cave floor, the floor, walls, and roof are lined with stainless steel cladding, which facilitates periodic washdown.

3.4.1.4 Applicable Experience

The BNFL site at Sellafield relies on crane zoning restrictions, speed controls and administrative controls to operate in-cave overhead cranes. The vitrification caves at Sellafield contain piping arrays, vessels and mechanical equipment, all of which are remotely replaceable using the in-cave cranes. The zoning restrictions prevent collisions during normal operations. Under remote maintenance, the zoning controls are less stringent. However, the vessels and associated piping and equipment are emptied and washed out before replacement. There is no comparison with the potential for erosion in the feed pipes to the melter as the glass at Sellafield is fed directly into the melter. Industrial experience shows that damage to pipework by cranes is a common occurrence. Previous experience at the Savannah River site with leaks of active material within process caves have resulted in control strategies incorporating a ventilation system with associated filtration, the tripping of pumping operations on indication of a leak by high sump alarms, and the use of remote visual observation (closed circuit television, CCTV) to help identify leaks (WSRC 1997).

3.4.2 Hazard Evaluation

3.4.2.1 Hazard Identification

For this example, the hazard arises from the dispersion of radioactive material released into the melter cave resulting from a breach of the melter feed line. This example was chosen based on the expectation that it could result in high exposure to facility workers and co-located workers and medium exposure to the public.

3.4.2.2 Event Sequence

Failure of the melter feed line was postulated in the Hazard Analysis Report (BNFL Inc. 1998e, p 5-131) and the Initial Safety Analysis Report (BNFL Inc. 1998f, p 4-132). This event was considered to be bounded by overfilling or leaking of the HLW melter vessel.

Failure of the feed line could include either a chronic release from a leak or an acute release from a pipe break. Potential initiators for failure of the feed line include:

- Loads dropped from overhead crane or power manipulator
- Catch feed line with crane hook, suspended load or power manipulator
- Feed line weld failure
- Erosion
- Corrosion
- Seismic
- Failure to install or replace feed line
- Improperly installed feed line
- Feed Line damaged by crane/power manipulator during maintenance

It was determined that the unmitigated dose consequences from the pipe leak were bounded by a pipe break (Smith 1999). Therefore, the scenario used for determining the severity level of the HLW melter feed line failure was a pipe break.

The pipe break event results in feed material falling onto the hot melter surface, which results in some feed material boiling dry and the remainder forming a pool on the cave floor. An airborne release rate was calculated resulting from four contributing mechanisms: impact of free fall of material, boiling of feed material contacting the hot melter surface, resuspension from dried material on the melter surface, and resuspension from the liquid pool on the cave floor.

Some of the airborne material is then released from the melter cave, via the cave ventilation and filtration system, to expose co-located workers and the public. In the event of loss of ventilation in the cave, the potential also exists for exposure to facility workers from backflow through cave penetrations.

3.4.2.3 Unmitigated Consequences

The following text and table summarize the results of the consequence calculation.

Table 3.4-1. Unmitigated Dose Consequences[a]

Population	Dose (rem)	Severity Level
Facility Worker	23[b]	SL-2
Co-located Worker	14	SL-2
Public	0.05	SL-4

[a] Dominant pathway is inhalation.
[b] Although the calculated dose to the facility worker is based on an 8-hour exposure, a more realistic exposure time is estimated at 2 hours (see Assumption 10 below).

The melter feed line failure is SL-2 based on the potential unmitigated consequences to the facility worker and the co-located worker. The target frequency associated with SL-2 is 10^{-4}/year.

Details of the consequence calculation are presented in Calculation No. CALC-W375HV-NS00004 (Smith 1999).

Assumptions made were:

1. The flow rate of 40 gph (150 L/h) used for calculating the unmitigated release is the combined average flow rate for both lines. Although the scenario assumed only one feed line failed, the combined average flow rate was used to account for the fact that only that one feed line could be operating at the 40 gph (150 L/h) at the time of failure. The total flow will be controlled based on the glass production rate of 1.5 t/d. **Design Assumption.**

2. Melter internal temperature = 1200 ºC. **Design Assumption.**

3. Melter top temperature = 150 ºC. **Design Assumption.** Some surfaces may be hotter. However, they are neither horizontal nor located such that a pipe break would pour straight onto them.

4. Maximum airborne concentration of 10 mg/m^3 in the cell from a liquid spill (BNFL plc 1997, Sheet 1.1). This concentration is used in determining the potential airborne concentrations outside the cell in the operating area and resultant dose to the facility worker.

5. For determining the unmitigated dose to a facility worker, a decontamination factor of 100 was applied to back flow through the cave sealed penetrations into the operating area. This assumes the cave ventilation is not operating (BNFL plc 1997, Sheet 6.4).

6. The determination of releases to the environment and doses to the co-located worker and the public are based on releases resulting from:

   - Entrainment and splatter from the free fall of the liquid
     The Airborne Release Fraction (ARF) for such a mechanism is given as 5.0×10^{-5} for free fall spill of slurries with an average Respirable Fraction (RF) of 0.8 (DOE 1994, Section 3.2.3.2).

   - Boiling of liquid from falling on the hot surface of the melter
     The Airborne Release Fraction (ARF) for such a mechanism is given as 2.0×10^{-3} for boiling liquids with an average Respirable Fraction (RF) of 1.0 (DOE 1994, Section 3.2.1.3).

   - Resuspension of dried material from the melter
     The Airborne Release Rate (ARR) for such a mechanism is given as 4.0×10^{-5}/h for suspension of powders with an average Respirable Fraction (RF) of 1.0 (DOE 1994, Section 4.4.4.1).

   - Resuspension of liquid from the cell floor
     The ARR for such a mechanism is given as 4.0×10^{-7}/h for resuspension from a liquid pool with an average Respirable Fraction (RF) of 1.0 (DOE 1994, Section 3.2.4.5).

7. For determining the unmitigated dose to the co-located worker and the public, a decontamination factor of 10 was applied for radioactive material released to the environment via the cell ventilation (BNFL plc 1997, Sheet 6.4).

8. The atmospheric dispersion coefficient crediting plume meander is given as 1.5×10^{-5} s/m^3 for the public and 8.55×10^{-3} s/m^3 for the co-located worker (at a distance of 100 m from the release). Credit is taken for both plume meander and building wake, given that the exposure to resuspended material is not instant and could last up to 24 hours (NRC 1982).

9. The radionuclide concentrations, other than cesium, are based on the inventory in tank 241-AZ-101 which provides the maximum unit liter dose for an inhalation pathway (the worst case pathway). The radionuclide concentrations in the waste received from tank 241-AZ-101 are based on the waste inventory (WHC 1997, Appendix D). The source term for cesium is based on the maximum concentration permitted within the 1500 W allowable heat load for the HLW glass canister (Smith 1999).

10. Although the dose calculated for the facility worker is based on being exposed to the unmitigated release for 8 hours, it is unlikely that a worker would remain in the immediate proximity of the cave penetrations through the cave wall (where the decontamination factor of 100 applies) for more than two hours. Since the concentration of radioactive material in the operating area will decrease with increasing distance from the penetrations, the unmitigated facility worker dose calculated is conservative.

3.4.2.4 Frequency of the Initiating Event

This analysis considers five primary ways to cause a breach of the melter feed line:

1. failure to replace the removed line during a planned replacement outage
2. improper replacement of the line such that it leaks upon restart
3. gradual erosion/failure of the line
4. damage to the line during maintenance
5. damage to the line from crane and power manipulator activities.

The unmitigated frequency estimate for a breach of the melter feed line is approximated as 0.1/year. This is a very conservative estimate based upon an unrealistic case assuming no credit for normal work controls for line inspection and replacement, as well as a lack of controls for maintenance activities and crane and power manipulator operations in the area. As such, conservative values are used which contribute to the value of 0.1/year. The frequency estimate is shown in further detail in Kolaczkowski (1999).

3.4.2.5 Common Cause and Common Mode Effects

The common causes or common mode effects that could result in failure of both feed lines simultaneously and that are identified as likely to be a significant contributor to the accident frequency were:

- the crane hook or load suspended from the crane or the power manipulator
- human error in the replacement of the feed lines and/or causing damage during maintenance.

These were among the initiators considered in developing the control strategy.

3.4.2.6 Natural Phenomena Hazards and Man Made External Events

3.4.2.6.1 Natural Phenomena

Natural phenomena hazards (NPH) and their treatment on a plant-wide basis are included in section 2.10. **Design Assumption.** Of these, seismic events are clear potential initiators for feed line failure, which needs to be addressed once the control strategy has been developed.

3.4.2.6.2 Man-Made External Events

Similarly, man-made hazards and their treatment on a plant-wide basis are also discussed in section 2.10. There are no man-made hazards that uniquely affect this event.

3.4.3 Control Strategy Development

3.4.3.1 Controls Considered

Controls were considered to prevent or mitigate the consequences of failure of the HLW melter feed line. The elements were identified as applying to a slow leak and/or line break event.

- Source Removal by Wash/Vacuum (leak). After a release, the leaked material needs to be removed to prevent a continuous source of contamination. A spray ring/wash down or vacuum system could be provided.

- Apply Fixative (leak). This would be an alternative to source removal. Instead of removing the leaked material, it would be sprayed or otherwise coated with some fixative to prevent further contamination.

- Double Wall Pipe with Leak Detection and Link with Flow Detection Instrument Below (leak). The outer pipe would contain any material that is released from the inner pipe and also confine it for detection by an appropriate leak monitoring system. In addition, detection of a leak would automatically turn off the air supply to the ADS pumps.

- Catch Pan (leak). A catch pan could collect a leak for either visual observation or some type of instrumented detection, prevent the leaked material from coming in contact with a hotter surface, and be washable or removable for ease of contamination control.

- Melter Insulation (leak). Insulation, especially on the top of the melter, will prevent contact of any released feed material with a very hot surface. This will minimize generation of airborne material since the release rate for particulates is comparatively low for gentle boiling versus violent, rapid boiling.

- Separation from Offgas Vent (leak). It is recognized that the melter vent will be very hot. Separation of the melter feed line from the vent is desired for the same reason as stated for melter insulation above. Either distance or some type of physical barrier could be used.

- Flow detection instrument with Interlock (break). Flow detection as close to the melter inlet as possible, which could use any of the following techniques: pressure, temperature, infrared and ultrasonic. This detection would be interlocked with the pump operation. The pressure system would put a sensor into the line and link to a transducer out of the cave. The temperature option would have thermocouples on the outside of the pipe and detect the change in temperature. The infrared system would look at an infrared image of the pipe and detect the change in temperature. The ultrasonic system would attach a detector to the pipe and look for the change in response as the liquor goes past.

- Zoning of Cranes and Power Manipulator (break). A signal will be fed from the pump when in operation that will prevent the cranes and power manipulator entering the zone in the immediate vicinity of the melter feed lines.

- Camera Looking in Melter (break). A camera could observe the flow of feed and condition of the cold cap within the melter. The camera would not need to be located within the melter itself but could view through ports. The absence of flow or decrease in cold cap would indicate failure of the melter feed line.

- Sump Level Detection (break). A large leak or catastrophic failure of the feed line would release material that could potentially reach the cave sump. Detection instrumentation in the sump would alert operations of a possible leak or spill.

- Mass Balance (break). A discrepancy between the mass of glass produced by the melter and the mass of glass forming material fed to the melter over the same time period (assuming a constant level in the melter) would indicate a leak in the melter feed line.

- Melter Dynamics (break). Loss of feed into the melter would result in noticeable changes in operational parameters. These could include temperature increase at the top of the melter, decrease in power to maintain temperature, decrease in melter offgas flow, and others.

- Protected High Integrity Lines (leak and break). The line at risk should be detailed to have the required life plus appropriate factor (e.g., the life of the melter x 2) and be replaced periodically, at least every time the melter is replaced. The line should be designed to prevent the crane hook or power manipulator from unintentionally engaging with the pipe. In addition, if these requirements do not result in a robust design, then the design should be further enhanced to protect the pipe from limited impact and inadvertent damage.

- Cave Structure (leak and break). The existing design of the cave will mitigate the release of material.

- Periodic Visual Inspection (leak and break). Periodic visual inspection of the feed line, melter feed tank, and melter sidewalls through cave windows would reveal the presence of leaks or line breaks.

- Cave Ventilation/Filtration (leak and break). Cave ventilation/filtration will provide control of particulates, either those generated directly by the release/leak or resuspended from dried feed material. It is assumed that the ventilation system includes multiple stage HEPA filters and has sufficient flow rate to maintain the required negative pressure respective to adjacent areas under all foreseen conditions.

- Cave Ventilation Monitors (leak and break). A radiation monitor would be located in the cave vent line to monitor the activity of the cave's off gas. An upward trend or significant step increase could indicate a leak.

3.4.3.2 Control Strategy Selection

Control strategy selection was based on a two-step process: first, clearly unrealistic control elements were deleted; second, engineering tradeoffs were considered to further down-select the options and a preferred control strategy was selected.

3.4.3.2.1. Step 1 (Initial Screen)

The merits of each of the potential controls described above was then considered, primarily against the following set of criteria:

- Effectiveness

- Practicability

- Reliability
- Demonstrability
- Compliance with laws and regulations
- Ability to comply with DOE/RL-96-0006, *General Radiological and Nuclear Safety Principles* (in particular, use of proven engineering practice, ease of providing inherent/passive safety features, radiation protection features, and avoidance of undue reliance on human actions).

The objective of this review was to identify the main advantages and disadvantages of each control, and also to eliminate those that were not considered viable in formulating a composite control strategy. The results of the process are shown in Table 3.4-2.

Table 3.4-2. Initial Evaluation

Control	**Advantages**	**Disadvantages**	**Compliance with Top-Level Principles**	**Further Consideration in Control Strategy**
Source Removal by Washing or Vacuum	Removes some contamination	Impractical – difficult to implement and demonstrate May make situation worse Not effective in preventing or mitigating event	No – requires operator action	No - impractical
Apply Fixative	Low cost, easy to apply and quick	Temporary Question on effectiveness-difficult to apply everywhere required Impractical – no easy way of controlling application	No – requires operator action	No - impractical
Double Wall Pipe with Leak Detection	Passive prevention Straight forward to implement Positive leak detection. Used extensively	Not effective containment for break (collision) May not be able to be applied over the full length of the line (i.e., at connectors)	Yes	Yes
Catch Pan	Low cost, localizes liquid spills	Not effective for squirts and not effective for some geometries	No –requires operator action to clean	No – not effective
Melter Insulation	Reduces evaporation. May reduce mobility of spill.	Impractical to insulate the total surface. Still leaves avenues for ingress to hot surfaces	Yes	No – not effective
Separation from Off Gas Vent	Reduces evaporation May reduce mobility of spill	Achievable separation is minimal – impractical Only effective for sprays	Yes	No – not practical

Table 3.4-2. Initial Evaluation

Control	Advantages	Disadvantages	Compliance with Top-Level Principles	Further Consideration in Control Strategy
Flow Detection instrument with Interlock	Provides quick detection and response to pipe break	Would not detect small leak Requires testing, calibration, and maintenance	Partial – is an active system.	Yes
Zoning of Cranes and Power Manipulator	Prevents cranes and power manipulator access during melter feed pumping to area containing feed lines	Would limit scope of cranes and power manipulator operations in-cave during pumping operations Does not prevent break during shutdown	Partial – is an active system	Yes
Camera Looking in Melter	Directly observe flow termination for breaks and changes in cold cap condition (indicates flow rate change)	Requires maintenance Not effective for small leaks Questionable visibility through melter lens Impractical - requires constant surveillance by operator	Partial – not proven technology. Active system, administrative control	No – impractical
Sump Level Detection	Indicates leak in cave if no other sources of liquid (i.e., cave wash down)	Not effective – Cannot identify leak source; leak may not get to the sump	Yes	No – not effective
Mass Balance	None	Not practical – not sufficiently sensitive Slow detection response Requires operator action	No – requires operator action	No – not practical
Melter Dynamics	Automatic detection	Not effective – not selective and slow response	No – requires operator action	No – not effective

Table 3.4-2. Initial Evaluation

Control	Advantages	Disadvantages	Compliance with Top-Level Principles	Further Consideration in Control Strategy
Protected High Integrity Lines	Passive. Prevention. Straightforward to implement. Practical and reliable	Protection not effective in all instances Can only demonstrate erosion resistance through modeling or long term testing	Partial – no defense in depth for collision	Yes
Cave Structure (walls, etc.)	Passive and mitigative Isolates event from operating area Contains contamination Robust	None	Yes	Yes
Periodic Visual Inspection	Locates leak or break	May not be effective for small leaks Human interpretation and action required – no immediate detection	Partial – requires human actions	Yes
Cave Ventilation/Filtration	Positive control of release	Requires testing and maintenance	Yes – reliable active system	Yes
Cave Ventilation Monitors	Detects mobile contamination	Cannot distinguish source Not effective	Partial – is an active system and not specific to pipe leak	No – not effective

The following controls remained to be considered in formulation of the control strategy to be adopted:

- Double wall pipe with leak detection
- Flow detection instrument with interlock
- Zoning of cranes and power manipulator
- Protected high integrity line
- Cave structure
- Periodic visual inspection
- Cave ventilation/filtration.

3.4.3.2.2. Step 2 (Engineering Screen)

The preferred strategy was then developed through an engineering evaluation of the alternatives. This took account of the following considerations to ensure a comprehensive approach in the context of other hazards and the overall design.

- Introduction of secondary hazards
- Impact on safety features provided to protect against other hazards
- Impact of other hazards upon the control strategy
- Robustness to other fault conditions and environments (including seismic and other design basis events)
- Passive or active, and if active, automatic or administrative/procedural – order of preference
- Robustness of any administrative controls required
- Cost
- Operability
- Maintainability
- Ease of justification (e.g., consistency with proven technology)

The considerations are presented in Table 3.4-3.

Table 3.4-3. Engineering Evaluation

Control	**Introduces Secondary Hazards**	**Impacts Safety Features for Other Hazards**	**Impact of Other Hazards on Control Strategy**	**Robust to Other Faults and Environments**	**Passive or Active**
Double Wall Pipe with Leak Detection	No	No	No	Yes	Active / Passive
Flow Detection Instrument with Interlock	No	No	Yes - a blocked line will also activate the interlock	Yes	Active
Zoning of Crane	No	No	No	Yes	Active
Protected High Integrity Lines	No	No	No	Yes	Passive
Cave Structure	No	No	No	Yes	Passive
Periodic Visual Inspection	No	No	No	Yes	Passive
Cave Ventilation/Filtration	Yes – accumulates material on filters that periodically require change out	No	Yes – fire	No – loss of power	Active

Table 3.4-3. Engineering Evaluation

Control	**Robustness of Administrative Controls**	**Cost**	**Operability**	**Maintainability**	**Ease of Justification**
Double wall pipe with leak detection	Yes – periodic testing required	Low	Well proven	Active maintenance	Not proven for this application
Flow detection instrument with interlock	Yes – periodic testing required	Low	Well proven. Possibility of spurious shutdowns	Active maintenance Susceptible to plugging	Easy to justify for catastrophic failure
Zoning of crane	Yes – periodic testing required	Low	Well proven	Active maintenance	Yes
Protected high integrity lines	NA	Low	Well proven	Requires periodic replacement	Yes
Cave structure	NA	Low (no additional – in present design)	Well proven	None required	Yes
Periodic visual inspection	Requires periodic operator surveillance and response	Low (no additional – in present design)	Well proven	None required	Yes
Cave Ventilation/ Filtration	Yes – periodic testing required	Low (no additional – in present design)	Well proven	Active maintenance – no new maintenance requirements imposed by this hazard	Yes

The only control strategy element eliminated as a result of the engineering screen was the double-walled pipe with leak detection. This control was dismissed because :

- May not be able to detect small leaks (could dry up before reaching sensor)
- Not effective for impact with crane or power manipulator.

3.4.3.2.3. Control Strategy Selected

In selecting a control strategy, there is a requirement to emphasize preventive over mitigative, passive over active, and automatic over procedural. For this example, protected high integrity lines and a crane and power manipulator zoning system are designed to prevent a leak or break. The remaining elements identified below as part of the control strategy selected provide mitigation in the event one or both of the feed lines does fail:

- high integrity line that is erosion and corrosion resistant and physically protected from damage by cranes and power manipulator,
- zoning of the cranes and power manipulator will prevent access into the immediate vicinity of the feed lines during pumping operations,
- flow detection instrument and interlock instruments will be located at the end of each feed line that will shut off the pump(s) in event of a loss of signal while pumping,
- cave structure will provide secondary containment in the event of a release from the line(s),
- periodic visual inspection through cave windows to look for evidence of leaks or breaks,
- cave ventilation/filtration system.

By providing both preventive and mitigative features, the selected control strategy provides defense in depth. Preventive measures are provided by zoning the cranes and power manipulator and by providing protected high integrity feed lines. In addition, there will be administrative controls in place to ensure the periodic replacement and re-start testing of the feed lines with water prior to the reintroduction of active material.

If one of the melter feed lines does break, the interlock will shut down the pump and minimize the amount of material released into the melter cave. The periodic visual inspection by the operator will provide a method of detecting and stopping a leak. Finally, the filtered cave ventilation system provides a further level of mitigation.

3.4.3.3 Structures, Systems, and Components that Implement the Control Strategy

The SSCs that implement the selected control strategy for the HLW melter feed line failure hazard are:

- Protected high integrity melter feed lines – replaced on a periodic basis and tested to confirm proper installation
- Cranes and power manipulator zoning controls – sensor on pump and trip module
- Flow detection instrument and interlock – sensor on feed line and trip module
- Cave structure walls, floor, and ceiling to confine material released from feed line failure; seals for all cave penetrations such as filters, manipulators, etc.
- Periodic visual inspection - through cave windows
- Cave ventilation – filters, fans and ducting

The selected control strategy is shown in Figure 3.4-2.

3.4.4 Safety Standards and Requirements

3.4.4.1 Reliability Targets

The reliability target for the overall control strategy is 1×10^{-4}/y based on an SL-2 event. This needs to be achieved by the combination of the preventive and mitigative parts of the strategy.

3.4.4.2 Performance Requirements

For ease of understanding, the overall reliability target can best be separated into two parts. These are 1) the reliability of the primary mitigative feature, the cave ventilation equipment that should easily achieve less than 1×10^{-2} probability of failure on demand; and 2) all the other aspects of the control strategy (protected high integrity line, flow interlock, cranes and power manipulator interlock, etc.) which either prevent the pipe breach altogether or prevent a small leak from growing or being undetected for a long time. This latter set of features needs to achieve the remaining apportionment of the overall 1×10^{-4}/y target frequency.

Other performance requirements for the individual features are covered below.

3.4.4.2.1. Protected High Integrity Line

The HLW melter feed lines must be capable of being remotely replaceable and effectively sealed. The lines and the remotely operated couplings that facilitate replacement shall be seismically qualified and resistant to erosion and corrosion for at least twice the melter life. A development program for the design of the feed lines must determine the required pipe size and most suitable material for transporting the corrosive and erosive feed. **Open Issue.** The line will be protected against inadvertent hook and power manipulator engagement and power manipulator jaw forces (crushing). The lines will be robust to protect against limited impact and manipulator interference. The lines must be capable of withstanding thermal stresses and distortions associated with being connected to the melter. It may be necessary to consider local cooling to achieve this requirement. **Open Issue**.

3.4.4.2.2. Cranes and Power Manipulator Interlock

If the pump is running, the cranes and power manipulator will not be allowed to operate in the area of the melter feed lines. If the crane and power manipulator are in the area, then the melter feed pump should not start. The interlock should fail safe, i.e., shut off pump.

3.4.4.2.3. Flow Detection Instrument With Interlock

The flow detection instrument shall be capable of detecting a no-flow condition and provide timely shutdown of the HLW melter feed pumps. A study must be conducted to select the technique to be used and to determine whether the instrument should be integrated with the pipe assembly. **Open Issue**

The interlock shall fail-safe; i.e., it should shut the pump off on failure.

3.4.4.2.4. Cave Structure

The melter cave structure shall be designed to maintain the confinement barrier in the event of a design basis earthquake. The melter cave penetrations shall be seismically qualified and be capable of withstanding higher air temperatures. The cave structure must be designed to provide a decontamination factor of 100 for backflow of material through sealed penetrations upon loss of cave ventilation.

3.4.4.2.5. Cave Windows

The cave windows shall provide a means of visually inspecting the melter feed lines for leaks or breaks.

3.4.4.2.6. Cave Ventilation/Filtration

The cave ventilation/filtration system shall be capable of:

- Ductwork to provide a decontamination factor of 10 as assumed in the unmitigated analysis (see section 3.4.2.3)
- removing aerosols and particulates, providing a decontamination factor of 10^5 for active ventilation/filtration.
- maintaining the melter cave at a negative pressure with respect to the occupied areas of the facility; redundant fans are required.

3.4.4.3 Administrative Measures

Administrative measures required to assure the selected control strategy are as follows.

Normal Operations

Normal operations will be conducted in accordance with approved operational safety requirements and in strict accordance with administrative and procedural control. Operators will be trained and assessed on the conduct of normal operations. Operational procedures, routine schedules, and records will augment training.
Operator procedures will be developed for the routine operations detailed below. The operator instruction provides a systematic approach to complete all the necessary activities. The operator instruction will detail roles and responsibilities, levels of authority, hazards and precautions, and operational decision points.

Operator Response to Abnormal Conditions

Operators will be trained to identify, diagnose and respond to abnormal operating conditions. Plant information will be relayed to the operator in such a manner to aid the operator in performing this duty. Typically, any deviation of the process from its normal operating condition will generate an alarm appropriate to its importance. This alarm will annunciate at the operator workstation or locally within the facility. Operational procedures will detail the:

- Actions the operator must perform to minimize the impact of the abnormality
- The potential initiators
- The follow up actions required when plant conditions have been stabilized

3.4.4.3.1. Feed Pipe Replacement

Operating procedures will require replacement of the melter feed pipes on a periodic basis, upon replacement of the melter as a minimum. The replacement frequency will be determined by the development program for the design of the feed pipe. **Open Issue.**

The key steps associated with the feed line replacement are:
- Establish disposal route for waste line
- Flush out the line prior to removal
- Replace line and check coupling and pipe integrity

The operational decision point of when to restart operations is dependent on satisfactory completion of line inspection and testing as detailed in Section 3.4.4.3.2.

3.4.4.3.2. Melter Restart

Operating procedures will require the testing of any newly fitted melter feed pipework with process water to test the adequacy of the connections and pipework. **Operating Assumption**. The melter feed system design allows for a process water flush through the melter feed lines.

3.4.4.3.3. Zoning of Cranes and Power Manipulator

Procedures for periodically testing the interlocks for cranes and power manipulator zoning will be required.

Arrangement for the examination, inspection, maintenance and testing of all ITS equipment will be managed through a plant maintenance schedule. All maintenance activities will be carried out using appropriate maintenance instructions.

3.4.4.3.4. Periodic Visual Inspection

A routine operating schedule will be established for the periodic visual inspection through the cave windows. A record will be taken and kept to demonstrate this operation has been completed.

3.4.4.3.5. Cave Ventilation/Filtration System

Periodic maintenance and testing of the ventilation/filtration system will be required. Operating procedures will also require manual switchover to a redundant filter bank upon alarm indicating high differential pressure across the filter bank.

3.4.4.4 Administrative Standards

Operation of the TWRS-P facility will be conducted in accordance with proven practices from BNFL operations in the UK and the US. Arrangements will be in place to maintain and demonstrate compliance with all Safety Criterion detailed within the authorization basis.

Administrative arrangements will provide the framework for how facility operations will be conducted for all modes of operation, including normal, maintenance, or emergency preparedness.

The conduct of operation guidelines will be generated by the tailored application of appropriate sections of the following standards:

IAEA 50-C-0, Code on the Safety of Nuclear Power Plants Operation
DOE Order 5480.19, Conduct of Operations Requirements for DOE Facilities
DOE Order 4330.4B, Guidelines for the Conduct of Maintenance at DOE Nuclear Facilities
Appropriate standards from the Institute for Nuclear Power Operations

This framework of conduct will be implemented through:

- Management and organizational structure

- Documents, records and certification, including response to abnormal operating conditions, key compliance recording and archiving.

- Structured training programs for all personnel, tailored to their roles and responsibility.

- Emergency preparedness implemented by having an emergency response structure, training, exercises and procedures.

- Incident reporting arrangements

- Safety documentation hierarchy, with appropriate flow down of information into operational documentation. All safety implications will be clearly identifiable within the operational procedures
- Quality assurance
- Arrangements for the examination, inspection, maintenance and testing of all ITS equipment
- Labeling of ITS equipment clearly on the facility.

3.4.4.5 Design Standards

The following section develops the specific standards for the selected SSCs but has not listed all the material and minor component standards.

3.4.4.5.1. Protected High Integrity Line

The following codes and standards would apply to the two HLW melter feed lines based on the high integrity performance requirement:

- ASME B31.3, *Process Piping,* the feed line systems will be designed to this standard's rules for category M fluid service. The handling features highlighted in the performance requirements will be designed from first principles with adherence to allowable stresses from the standard above.

3.4.4.5.2. Cave Structure

The cave structure is required for confinement of a material release associated with a feed line failure. The cave structure is assumed to remain intact for confinement during the seismic event. In order to meet these performance requirements, the structure is categorized as PC-3, in accordance with DOE-STD-1021, *Natural Phenomenal Hazards Performance Categorization Guidelines for Structures, Systems, and Components*. The NPH event loads will be determined in accordance with the following codes and standards:

> DOE-STD-1020, Natural *Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*
>
> ASCE 4, Seismic *Analysis of Safety-Related Nuclear Structures and Commentary*
>
> ASCE 7, Minimum *Design Loads for Buildings and Other Structures*

The following standards have been selected for design of the structural steel and concrete to ensure that the confinement barriers will not be compromised. These standards provide more conservative design allowables and prescribe more conservative design methods than those provided by model building codes. The structural elements resulting from designing with these standards will provide a robust structure, which will provide a higher level of reliability during the design basis event.

> ANSI N690, Specification *for the Design, Fabrication, and Erection of Steel Safety-Related Structure for Nuclear Facilities*

ACI 349, *Code Requirements for Nuclear Safety Related Concrete Structures*

3.4.4.5.3. Cave Ventilation Extract System

The melter cave ventilation extract system, plus its associated instrumentation, will maintain the melter cave at a negative pressure with respect to the occupied areas of the facility. The system will also remove aerosols and particulates from the ventilation exhaust stream prior to its discharge to the atmosphere. The discharge will be from an elevated release point through a continuously monitored and sampled exhaust stack. This cascaded airflow and filtration ensure that activity backflow from the melter cave to occupied areas does not occur. HEPA filters at the air inlet opening between the operating areas provide a physical barrier to activity backflow into the operating area. The cave ventilation extract system components will be designed in accordance with the following:

Fans	ASME AG-1*	*Code on Nuclear Air and Gas Treatment, Section BA*
HEPA Filter	ASME AG-1	*Code on Nuclear Air and Gas Treatment, Section FC*
Filter Frames	ASME AG-1	*Code on Nuclear Air and Gas Treatment, Section FG*
Ductwork	ASME AG-1	*Code on Nuclear Air and Gas Treatment, Section SA*
	ASME N509*	*Nuclear Power Plant Air-Cleaning Units and Components*
	ASME N510*	*Testing of Nuclear Air Cleaning Systems*

* WAC 246-247 referenced these codes and standards. ASME AG-1 provides code documents that specify the requirements for design, fabrication, inspection, and testing of air cleaning and conditioning components and appurtenances, as well as air cleaning components used in engineering safety systems in nuclear facilities. AG-1 was developed by nuclear steam system suppliers, operating owners, architect/engineers, members of the Nuclear Regulatory Commission, and individuals with general interest. ASME N509 and N510 provide similar requirements.

3.4.4.5.4. Electrical Supply System

Based on the robust configuration of both the onsite and offsite electrical supply systems, the target reliability is readily attainable using the below listed industrial electrical standards. These standards pertain to the electrical components (e.g., switchgear, motor control centers, wiring) necessary to provide reliable electric power.

IEEE-141, *Recommended Practice for Electric Power Distribution for Industrial Plants*
IEEE-142, *Recommended Practice for Grounding of Industrial and Commercial Power Systems*
IEEE-446, *Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications*
IEEE-493, *Recommended Practice for Design of Reliable Industrial and Commercial Power Systems*
ANSI/IEEE-C37, *Circuit Breakers, Switchgear, Substation, and Fuses*
ANSI/IEE-C57, *Distribution, Power, and Regulating Transformers*
NFPA-497, *Recommended Practice for Classification of Hazardous Locations for Electrical Installations in Chemical Process Areas*
NEMA-250, *Enclosures for Electrical Equipment (1000 V maximum)*
NEMA-MGI, *Motors and Generators*

NEMA-WC, *Wire and Cable Standards*
NEMA-ICS 1, *Industrial Control and Systems General Requirements*
29 CFR 1910 Subpart S, *Occupational Safety and Health Standards, Electrical*

3.4.4.5.5. Instrumentation and Controls Interlocks

The two mechanical/electrical interlocks (crane zoning and flow detector both with pump operation) will be specific designs to the following standard:

- ISA S84.01 Application of Safety Instrumented Systems for the Process Industries

3.4.4.6 Standards Not Cited in SRD

The following standards are not currently listed in the SRD (BNFL Inc., 1998g):

ANSI N690, *Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structure for Nuclear Facilities*
IAEA 50-C-0, *Code on the Safety of Nuclear Power Plants Operation*
DOE Order 5480.19, *Conduct of Operations Requirements for DOE Facilities*
DOE Order 4330.4B, *Guidelines for the Conduct of Maintenance at DOE Nuclear Facilities*
ASME AG-1, *Code on Nuclear Air and Gas Treatment*
IEEE-141, *Recommended Practice for Electric Power Distribution for Industrial Plants*
IEEE-142, *Recommended Practice for Grounding of Industrial and Commercial Power Systems*
IEEE-446, *Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications*
IEEE-493, *Recommended Practice for Design of Reliable Industrial and Commercial Power Systems*
ANSI/IEEE-C37, *Circuit Breakers, Switchgear, Substation, and Fuses*
ANSI/IEE-C57, *Distribution, Power, and Regulating Transformers*
NFPA-497, *Recommended Practice for Classification of Hazardous Locations for Electrical Installations in Chemical Process Areas*
NEMA-250, *Enclosures for Electrical Equipment (1000 V maximum)*
NEMA-MGI, *Motors and Generators*
NEMA-WC, *Wire and Cable Standards*
NEMA-ICS 1, *Industrial Control and Systems General Requirements*
29 CFR 1910 Subpart S, *Occupational Safety and Health Standards, Electrical*

3.4.5 Control Strategy Assessment

3.4.5.1 Performance Against Common Cause and Common Mode Effects

<u>Seismic</u>

It has been identified that a seismic event is a possible initiator of the failure of the HLW feed line independent of the frequency associated with other failure modes. However, should the seismic event be of sufficient magnitude to cause the feed line to break, the pump flow will also likely shut down due to loss of power to the pumps themselves or due to the flow interlock, which will fail safe on loss of power. Given it is not possible to be positive about such performance at this stage of design, it is simpler to seismically qualify the line. **Design Assumption.**

Furthermore, it is expected that when the seismic design requirements of the melter itself are examined in a later stage of design, this will include an integrated review of the lines into the melter as well. Hence, at this time the above design assumption is considered an **Open Issue** dependent on an integrated design review of the melter design.

<u>Aircraft Strike</u>

The HAR (BNFL Inc. 1998c) derives a frequency for aircraft crash into the TWRS facility as 4.5E-6/y. This is below the SL-2 target frequency of 10^{-4}/y and need not be considered further.

3.4.5.2 Comparison with Top-Level Principles

As a final test, the preferred strategy is evaluated against a set of relevant top level radiological, nuclear and process safety standards and principles (DOE-RL 1998b), as laid out below.

3.4.5.2.1. Defense in Depth (DOE-RL 1998b, 4.1.1.1)

Defense in depth is one of the general radiological and nuclear safety principles in DOE/RL-96-006 (DOE-RL 1998b). SRD Volume II, Appendix B contains the BNFL *Implementing Standard for Defense in Depth* (BNFL Inc. 1998g). This Implementing Standard governs application of the defense in depth principle on the TWRS-P project.

To satisfy the application of defense in depth, the Implementing Standard requires that the elements of the control strategy must ensure "…that no one level of protection is completely relied upon to ensure safe operation. This safety strategy provides multiple levels of protection to prevent or mitigate an unintended release of radioactive material to the environment."

DOE/RL-96-0006 formulates the defense in depth principle in terms of the following six sub-principles:

- Defense in depth
- Prevention
- Control
- Mitigation
- Automatic Systems
- Human Aspects

The implementing standard governs application of the defense in depth principle on the TWRS-P project and addresses each of the six subprinciples in DOE-RL 1998b. The following paragraphs describe application of the Implementing Standard for Defense in Depth to the control strategy for the HLW melter feed line failure.

1. Defense in Depth (DOE-RL 1998b, 4.1.1.1)

DOE/RL-96-0006, Section 4.1.1.1, requires the following:

"To compensate for potential human and mechanical failures, a defense-in-depth strategy should be applied to the facility commensurate with the hazards such that assured safety is vested in multiple, independent safety provisions, not one of which is to be relied upon excessively to protect the public, the workers, or the environment. This strategy should be applied to the design and operation of the facility."

Section 3.0 of the BNFL Inc. Implementing Standard for Defense in Depth addresses this aspect of the defense in depth principle specifically. For SL-2 events, Section 3.0 of the Implementing Standard for Defense in Depth requires:

- Two or more independent physical barriers to confine the radioactive material
- Consideration of the single failure criterion
- A target frequency of 1.0 x 10^{-4}/y for the SL-2 consequences

The control strategy includes two physical barriers against the release of radioactivity from the melter cave. The first barrier is the high integrity melter feed line itself; the second barrier consists of the cave structure and ventilation/filtration system.

The single failure criterion in the Implementing Standard requires that, given an initiating event, the control strategy must be able to tolerate a single failure of any single active component in the short term. The control strategy must also be able to tolerate a single passive failure in the long term. The single passive failure is to be a mechanistic failure (for example, pump seal leakage); the single passive failure is not a deterministic failure (e.g., a pipe break).

This example considered two initiating events: failure of the feed line as a result of erosion and failure of the feed line as a result of a crane impact. The control strategy satisfies the single failure criterion given the erosion or crane strike failure as the initiating event. The C5 extract system provides the ventilation exhaust from the cave. The control strategy and the corresponding frequency analysis takes credit for the two 100% fans and dual off-site power supplies. In addition, the C5 extract system has emergency power. Therefore, the C5 extract is not vulnerable to single active failures. Since the melter feed lines will be seismically qualified, the control strategy is not vulnerable to single failure from a seismic event.

The control strategy includes elements that reduce the probability that a feed line failure could occur. These elements are as follows:

- An interlock between the cranes and power manipulators and the feed pumps that will prevent them from entering the zone in the vicinity of the melter feed lines when the feed pump is in operation

- A feed line replacement program with a schedule that provides margin with respect to the predicted life of the feed line

- A program to test melter feed lines with process water before they are put into service with melter feed.

The control strategy also includes elements that will mitigate the consequences of a melter feed line failure. These elements are as follows:

- The confinement provided by the cell structure and associated filtered ventilation exhaust
- A transfer pump interlock that limits the amount of material released in the event of feed line failure
- Periodic visual inspection to identify and respond to leaks

Section 3.4.5.6 shows that the control strategy reduces the frequency of SL-2 consequences from melter feed line failure to less than 6 x 10^{-6}/y. This satisfies the target frequency in the Implementing Standard by a wide margin.

Sections 3.4.5.3 and 3.4.5.4 show that the mitigating elements of the control strategy reduce the consequence from a pipe failure to SL-4. The frequency of a line rupture is 5 x 10^{-3}/y, which is well within the Implementing Standard target frequency of 1 x 10^{-1}/y for SL-4 events.

Based on the results of the frequency estimate, the control strategy meets the target frequency with a large margin. Also, the frequency estimates indicate that the control strategy does not place excessive reliance on any single element to achieve this result.

2. Prevention (DOE-RL 1998b, 4.1.1.2)

The emphasis in the selected control strategy is the prevention of the release by provision of protected high integrity HLW feed lines, and the zoning of the cranes and power manipulator that give an acceptably low frequency of failure. The protected high integrity pipes will be robustly designed and installed to achieve their purpose when subjected to the range of operating and environmental conditions expected during normal operations and anticipated operational occurrences and will be replaced periodically over a time period as yet to be determined by development work. **Open Issue**. Should it not be possible to establish a realistic time period over which the pipe may be installed without risk of leakage as a result of corrosion, the requirement for coaxial pipes will be considered.

3. Control (DOE-RL 1998b, 4.1.1.3)

The chemistry of the feed stream, pressure and temperature will be controlled within limits that provide adequate margin to the capability of the lines to continue their safe function of containing the melter feed stream for their expected lifetime. The instrumentation required for the zoning of the cranes and power manipulator will be designed to withstand the environmental conditions within the melter cave.

The frequency of demands placed upon the active important to safety SSCs within the control strategy is low due to the protected high integrity line.

4. Mitigation (DOE-RL 1998b, 4.1.1.4)

The control strategy provides mitigation in the form of the cave structure and ventilation/filtration system, which reduces the amount of radioactive material reaching the external environment, and automatic systems, which limit the potential for spread of contamination.

5. Automatic Systems (DOE-RL 1998b, 4.1.1.5)

The flow detection instrument is interlocked with the feed pumps to automatically shut down the pump(s) in the event of a loss of signal to limit the amount of material released should the feed line fail.

6. Human Aspects (DOE-RL 1998b, 4.1.1.6)

Operating procedures will require operators to routinely change the feed pipework when scheduled and to test newly fitted melter feed pipework for leakage and adequacy of connection using the flow detection instrumentation. In the event operators are alerted to the failure or malfunction of equipment, operating procedures impose administrative controls to limit the spread of radioactive contamination. The human aspects are associated with changing the melter feed pipeline and testing for proper installation, and performing visual inspections and taking appropriate response actions.

Since the severity level for the melter feed line hazard is SL-2, per section 2.6.2 of the Implementing Standard for Defense in Depth, the control strategy must be reviewed against the human factors engineering criteria in IEEE Standard 1023-1988 6.1.1, as tailored by the Implementing Standard. **Open Issue.**

3.4.5.2.2. Operating Experience and Safety Research (DOE-RL 1998b, 4.1.2.4)

The use of protected high integrity pipework for the transfer of hazardous liquids is commonly employed by a number of industries. The use of physical protection around vulnerable equipment and the practice of zoning a crane are commonly employed within the nuclear industry. The provision of ventilation/filtration of the cave air is also common practice within the nuclear industry and is widely employed. The use of preventive maintenance and pre-start testing is also widely used in industry. Thus, the adopted methods build on operating experience.

3.4.5.2.3. Proven Engineering Practices (DOE-RL 1998b, 4.2.2.1)

The control strategy elements, physical barriers, automatic systems, and adherence to operating procedures in the event of an off-normal event are all practices widely used in the transfer of HLW. Methods used for implementing the control strategies will use proven engineering practice, including over 40 years of Hanford operating experience.

3.4.5.2.4. Common Mode/Common Cause Failure (DOE-RL 1998b, 4.2.2.2)

Damage to both HLW feed lines could be caused by the in-cave crane hooks or power manipulator or any items being carried by the cranes or power manipulator. However, provision of the flow detection instrument with interlock to the air supply for the ADS pumps will minimize the consequences of such an event. In addition, this flow detection instrument will fail-safe and will turn off the air supply on loss of power.

3.4.5.2.5. Safety System Design and Qualification (DOE-RL 1998b, 4.2.2.3)

The operating conditions for the SSCs are known and addressed in the design. Effects such as aging are well characterized for equipment of the type selected.

3.4.5.2.6. Radiation Protection Features (DOE-RL 1998b, 4.2.3.2)

The control strategy provides for confinement of material released. The control strategy has been subjected to an ALARA design review, which concluded that the selected strategy has no adverse ALARA impact (Pisarcik 1999).

3.4.5.2.7. Deactivation, Decontamination, and Decommissioning (DOE-RL 1998b, 4.2.3.3)

None of the control strategy elements complicate Deactivation, Decontamination, and Decommissioning.

3.4.5.2.8. Emergency Preparedness - Support Facilities (DOE-RL 1998b, 4.2.4)

The strategy has no foreseeable impact on the control room or emergency response center that may require to be manned after an event.

3.4.5.2.9. Inherent/Passive Safety Characteristics (DOE-RL 1998b, 4.2.5)

The protected high integrity lines provide passive safety, with the balance of the control strategy providing proven reliability.

3.4.5.2.10. Human Error (DOE-RL 1998b, 4.2.6.1)

Since active mitigation is provided for the pipe break, no human interaction is required. Failure of the operator to take action resulting from visual observation of a leak, to carry out preventive maintenance, or pre-testing of the newly installed line, is compensated for by active cave ventilation.

3.4.5.2.11. Instrumentation and Control Design (DOE-RL 1998b, 4.2.6.2)

Instrumentation is provided to control the movement of the cranes and power manipulator during pumping operations and to shut down the melter feed pump in event of a pipe break.

3.4.5.2.12. Safety Status (DOE-RL 1998b, 4.2.6.3)

Monitoring and alarm capability will be provided at the control room that alerts the operator to a high differential pressure across the HEPA filters. The control room display will be clear and unambiguous.

3.4.5.2.13. Reliability (DOE-RL 1998b, 4.2.7.1)

The reliability target has been met by this control strategy.

3.4.5.2.14. Availability, Maintainability, and Inspection (DOE-RL 1998b, 4.2.7.2)

The equipment specified is well suited to, and has experience of being subjected to, well-characterized inspection, testing, and maintenance regimes.

3.4.5.2.15. Pre-Operational Testing (DOE-RL 1998b, 4.2.8)

The control strategy is amenable to pre-operational testing of its elements, and experience of this exists for these elements.

3.4.5.3 Mitigated Consequences

The mitigated consequences are developed in Smith (1999) and take credit for operation of the cave ventilation. The following is a summary of the results:

Mitigated Dose Consequences[a]

Population	Dose (rem)	Severity Level
Facility Worker	0.14	SL-4
Co-located Worker	3.7×10^{-5}	SL-4
Public	4.3×10^{-8}	SL-4

[a]Dominant pathway is inhalation.

3.4.5.4 Frequency of the Mitigated Event

The anticipated controls to prevent melter feed line failure are applied to the analysis to determine the frequency of the mitigated event, crediting only the preventive mechanisms. This frequency is pessimistically estimated to be no higher than 5×10^{-3}/y and, conservatively, considers both failure to prevent minor leaks as well as failure to prevent gross pipe failure. This frequency estimate credits the following control features:

- Protected high integrity pipe
- Functional testing following replacement of pipe
- Cranes and power manipulator zoning
- Detection of leaks before they become significant

3.4.5.5 Consequences with Failure of the Control Strategy (Including Mitigation)

This is identical to the unmitigated consequences as described in Section 3.4.2.3.

3.4.5.6 Frequency of Control Strategy Failure

The frequency of failure for the entire control strategy including all the controls to prevent or mitigate the melter feed line failure (beyond the existing cave structure) is estimated at approximately 6×10^{-6}/year. This estimate specifically takes credit for the following aspects of the control strategy:

- Simple ventilation system with two parallel filter trains (no backup power nor automatic start features for redundant components). Two 100% capacity fans provide motive power for either filtration train.
- An operational requirement to replace the piping (which shall be high integrity piping) on a periodic basis (when the melter is replaced as a minimum)
- Procedures, qualified staff, and a follow-up test requirement to ensure proper installation of replacement pipe before processing is restarted
- Procedures and qualified staff to perform maintenance or crane operations when in the vicinity of the melter and surrounding piping and instruments
- Zoning of cranes and power manipulator operations with a simple design interlock so as to not allow coincident pump running with the crane near the area of the melter and feed line
- A simple monitor device and circuit (to be designed) to detect major failure of the pipe (e.g., rupture) which will shutdown the pump upstream of the feed line.
- Visual inspection at least once a shift (8 hours) to look for leaks.

The 6×10^{-6}/y result is dominated by undetected damage to the piping during maintenance (which should result in only minor leakage at worst) followed by resumption of processing and the operator does not detect the leakage and shut down the system during the shift, coincident with common failures of both ventilation fans such as due to loss of power or other fan equipment common cause failure modes. To actually result in the unmitigated consequences discussed in section 3.4.2.3, the expected minor leak due to undetected maintenance damage would have to become significantly larger before the pumping system is shut down or the ventilation system is restored to service. This "unquantified" consideration provides additional argument that the actual frequency of failure of the entire control strategy is less than the 6×10^{-6}/y cited above (Kolaczkowski 1999).

The assessment does not address seismic hazards. However, the melter feed lines will be seismically qualified, as discussed in Section 3.4.4.2.1.

The following summarize the results for this event:

Summary of Results (Mitigated[a])

Population	Dose (rem)	Severity Level	Frequency (y^{-1})
Facility Worker	0.14	SL-4	$<5 \times 10^{-3}$
Co-located Worker	3.75×10^{-5}	SL-4	$<5 \times 10^{-3}$
Public	4.3×10^{-8}	SL-4	$<5 \times 10^{-3}$

[a]Dominant pathway is inhalation
[b]Ventilation is successful

Summary of Results with Failure of Control Strategy[a]

Population	Dose (rem)	Severity Level	Frequency (y^{-1})
Facility Worker	23[b]	SL-2	6×10^{-6}
Co-located Worker	14	SL-2	6×10^{-6}
Public	0.05	SL-4	6×10^{-6}

[a]Dominant pathway is inhalation
[b]Although the calculated dose to the facility worker is based on an 8-hour exposure, a more realistic exposure time is estimated at 2 hours

3.4.6 Conclusions and Open Issues

3.4.6.1 Conclusions

A break of a HLW melter feed line has been analyzed. The break is assumed to result in entrainment and resuspension of activity in the cave environment. A control strategy has been developed that provides an acceptable level of protection for the facility worker, the co-located worker, and the public. The control strategy is summarized in Table 3.4-4.

The control strategy results in an event frequency of 6×10^{-6}/y which satisfies the target frequency of 10^{-4}/y. This strategy includes active and passive systems, prevention, mitigation and administrative controls, thus providing defense in depth.

3.4.6.2 Open Issues

The open issues that require resolution during design development are:

1. Determine Cave Ambient Temperature. The actual temperature in the HLW melter cave must be calculated when the cell layout and ventilation system design is finalized. This information will be used to determine if there is any impact on material selection.

2. Evaluation of Thermal Stresses and Distortion. Evaluate the capability of the melter feed lines to withstand the thermal stresses and distortions associated with being connected to the melter.

3. Feed Pipe Design. A development program for the design of the feed lines is planned to determine the required size of the pipe and most suitable materials for transporting the corrosive and erosive feed.

4. Selection Of Flow Detection Instrument. A study must be conducted to:

   a) select an appropriate instrument for detecting a no-flow condition in the HLW melter feed line and
   b) determine whether the instrument should be integrated with the pipe assembly.

5. Frequency For Replacement Of Feed Lines. Frequency for replacing the melter feed lines must be determined during detailed design activities.

6. Integrated Review of the Required Performance of the Feed Lines and the Melter. When the seismic design requirements of the melter are examined in a later stage of design, this will involve an integrated review of the required performance of the feed lines and the melter.

7. Review of Control Strategy Against IEEE Standard 1023-1988. The control strategy must be reviewed against the human factors engineering criteria in IEEE Standard 1023-1988 6.1.1, as tailored by the Implementing Standard.

Table 3.4-4. Control Strategy Summary

Hazard Description: HLW Melter Feed Line Failure				**Initiator:** Collision of Crane Hook with Feed Line(s)	
Selected Control Strategy	**Important-to-Safety SSCs**	**Safety Functions**	**Design Safety Features**	**Design Assumptions**	**Operational Assumptions**
Overall		To prevent HLW melter feed line failure To mitigate consequences of feed line failure			
Prevention of HLW melter feed line failure	Protected high integrity HLW Melter Feed lines	To provide primary containment for the HLW	Seismically qualified lines and couplings Protected against inadvertent damage by cranes or power manipulator Corrosion/ erosion resistant Lines remotely replaced with effective seals on a periodic basis	Stainless steel tubing Design life of feed line twice that of melter	Procedure will exist that requires feed lines to be replaced along with the melter, as a minimum frequency Procedure will also exist that require cold testing of newly installed lines to confirm proper installation
Prevention of HLW melter feed line failure	Zoning of crane	To prevent crane access to immediate vicinity of feed lines during pumping operations	Prevention of potential collisions while pumping feed	Crane access to area near melter feed line not required while pumping feed	Operating procedures required for periodic testing of interlocks

Table 3.4-4. Control Strategy Summary

Hazard Description: **HLW Melter Feed Line Failure**				**Initiator:** **Collision of Crane Hook with Feed Line(s)**	
Selected Control Strategy	**Important-to-Safety SSCs**	**Safety Functions**	**Design Safety Features**	**Design Assumptions**	**Operational Assumptions**
Mitigation of feed line failure	Shielded cave structure	Provide secondary containment in the event of a leak	Seismically qualified, sufficient thickness to provide shielding, minimal or sealed penetrations Provide decontamination factor of 100 for backflow into operating area with no cave ventilation Cave penetrations seismically qualified and capable of withstanding higher air temperatures	Cave will not be accessible to operators	
	Ventilation fans and ductwork	Provide a contained route for removal of airborne contamination from the cave	Ductwork to provide decontamination factor of 10 with no active cave ventilation/filtration Two100% fans		
	Filters	Provision of a barrier against release to atmosphere	Two parallel filter trains, each with 100% capacity Filtration to provide decontamination factor of 10^5 Filter differential pressure monitoring and alarm		Procedures will exist to require manual switchover to redundant filter bank upon alarm

Table 3.4-4. Control Strategy Summary

Hazard Description: HLW Melter Feed Line Failure				**Initiator:** Collision of Crane Hook with Feed Line(s)	
Selected Control Strategy	**Important-to-Safety SSCs**	**Safety Functions**	**Design Safety Features**	**Design Assumptions**	**Operational Assumptions**
Mitigation of feed line failure	Flow detection instrument with interlock	To shut off air for ADS pumps upon loss of flow	Detection of absence of flow to trigger cutoff of compressed air to melter feed pumps	Interlock fails safe	
Mitigation of feed line failure	Cave window	Periodic visual inspection and response action for leak	Provide multiple windows for different viewing perspectives	Cell layout conducive to visual inspection	Procedure will exist to identify inspection and response actions

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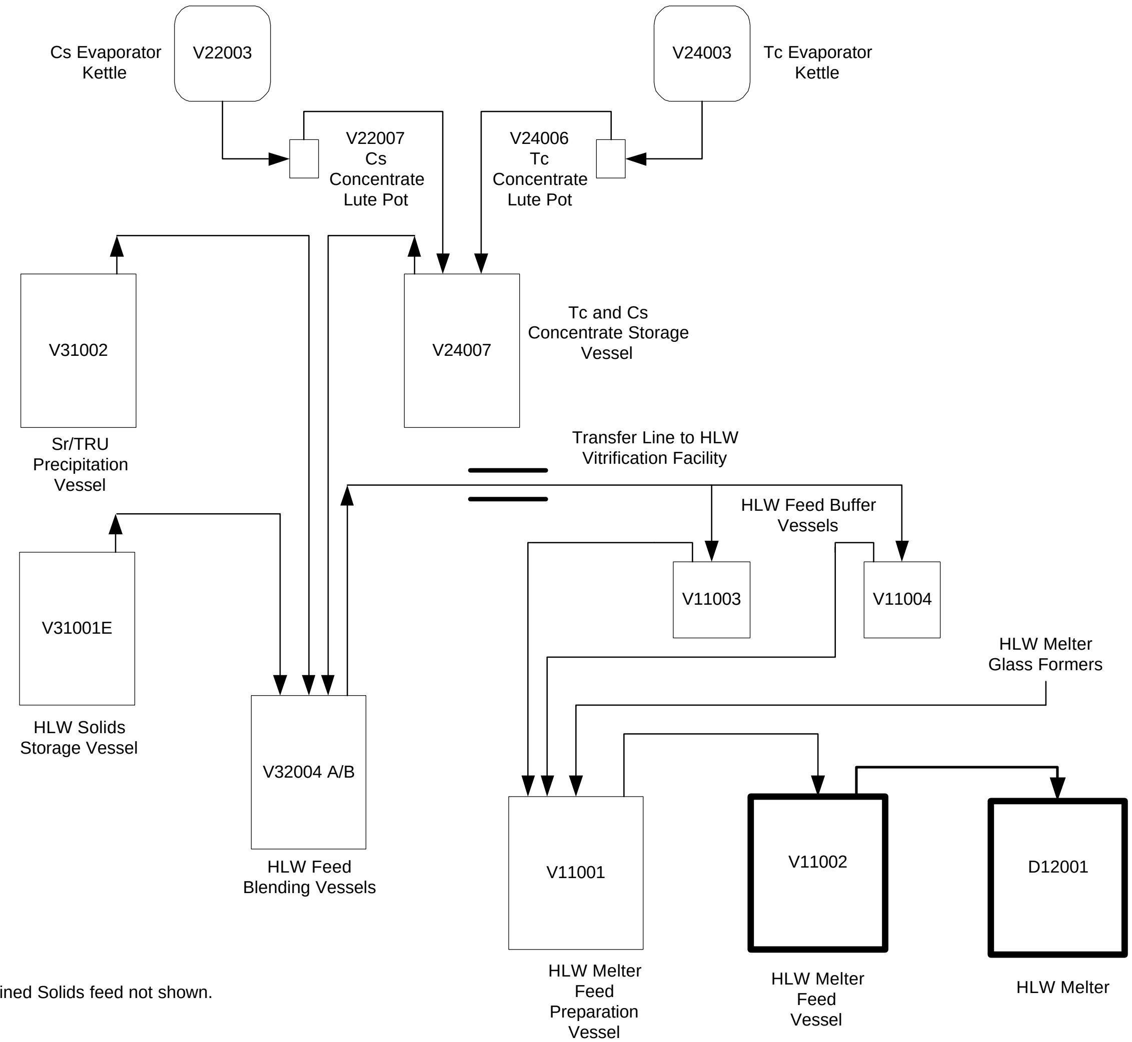
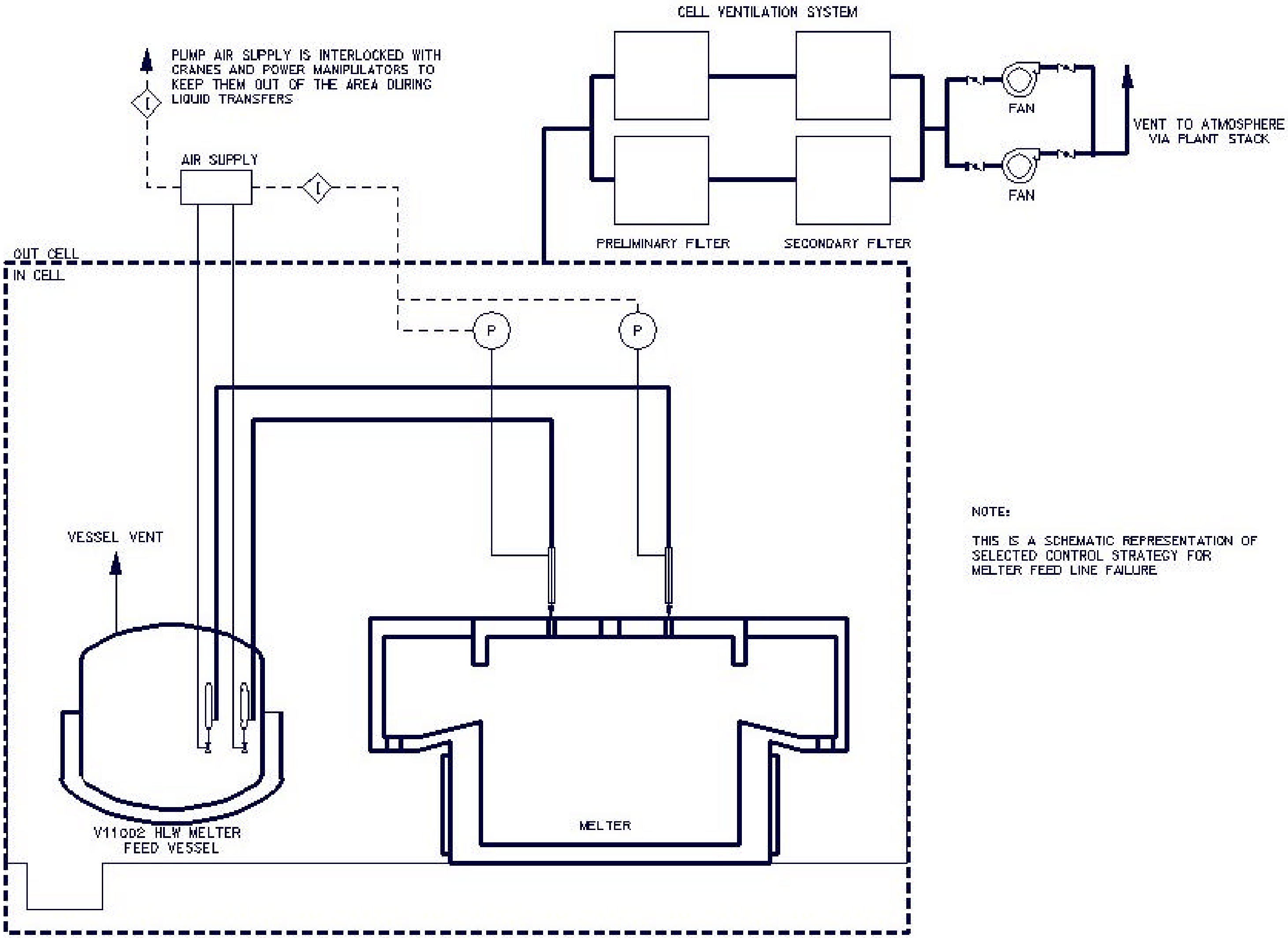
Figure 3.4-1. HLW Melter Feed Preparation System



Note: Optional Entrained Solids feed not shown.

Figure 3.4-2. Control Strategy Schematic



NOTE:

THIS IS A SCHEMATIC REPRESENTATION OF SELECTED CONTROL STRATEGY FOR MELTER FEED LINE FAILURE